(1)

NASA Technical Memorandum 78695

Progress in Supersonic Cruise Aircraft Technology

Cornelius Driver

MAY 1978

NASA

NASA Technical Memorandum 78695

Progress in Supersonic Cruise Aircraft Technology

Cornelius Driver
Langley Research Center
Hampton, Virginia

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Office

1978

SUMMARY

The Supersonic Cruise Aircraft Research (SCAR) program has identified significant improvements in the technology areas of propulsion, aerodynamics, structures, take-off and landing procedures, and advanced configuration concepts. These technology areas require significant further development before they are ready for application to a commercial aircraft. However, they may answer the adverse factors that were instrumental in the cancellation of the National Supersonic Transport (SST) program. They offer the promise of an advanced SST family of aircraft which may be environmentally acceptable, have flexible range-payload capability, and be economically viable. Further development requires an augmented SCAR technology program.

INTRODUCTION

This paper is a brief overview of the highlights of the NASA Supersonic Technology program. This program was generated about a year after Congress cancelled the National Supersonic Transport (SST) program in 1971. The Advanced Supersonic Technology program was conceived to preserve the base of knowledge developed during the SST program and to build on this technical base in an orderly way, thus preserving the capability to respond to the commercial supersonic challenge in the future. The present name of this advanced Supersonic Technology program is Supersonic Cruise Aircraft Research (SCAR). The results of the first four years of effort were reported in November 1976 at the SCAR conference at Langley Research Center, where 50 technical papers were presented (ref. 1).

Two areas are not discussed in this paper - sonic boom and upper atmosphere pollution. The large long-range airplanes being considered would be primarily used on over-water routes where very low boom levels are not required. In general, modest subsonic legs to avoid over-land booms can be accommodated without significant economic penalty. The upper atmosphere pollution area has been addressed by the Climatic Impact Assessment Program (CIAP) study (ref. 2) and the High Altitude Pollution Program (HAPP) study (ref. 3). The most recent results (ref. 4) indicate that the NO_x impact on the ozone problem is much better understood than in 1971. The impact of the supersonic transport is very small. Indeed, it may even increase the ozone level.

One of the problems inherent in a technology program is a method for quantifying progress. The method being used by the contractors and in-house at Langley is the development of reference airplane configurations (fig. 1). These show the improvement obtained in range, payload, or gross take-off weight, or economics through better engines, structures, or aerodynamics. This reference concept is also utilized to study airframe-propulsion integration problems, to measure take-off and landing noise improvements, and even

to develop new flight procedures for areas like noise reduction. It should be clearly recognized, however, what these reference airplanes are not. They are not preliminary designs for an airplane program. They are not the configurations that anyone would build or offer to the world airlines. Airplane designs for those purposes require depth of development and substantiation several orders of magnitude greater than that required for realistic technology measurement purposes. When airplanes are referred to in this paper, recognize that they are for reference purposes, for measurement of improvements, and for increased understanding of the problem areas.

Problems such as marginal range/payload capability, marginally acceptable take-off and landing noise, flutter, and unknown high altitude pollution effects are a serious detriment to any airplane program. These problems existed at the end of the SST program and provided focal points for the implementation of the technology program to be described in abbreviated fashion in this paper. The technology areas to be reviewed are propulsion, aerodynamics, structures, operating procedures, and advanced concepts.

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) with the equivalent values given parenthetically in the U.S. Customary Units.

PROPULSION

The heart of any advanced airplane is the propulsion system. Both the U.S. SST and the Concorde used an afterburning turbojet propulsion system. The Rolls-Royce Olympus engine in the Concorde is a very advanced engine with an overall efficiercy approximately 7 percent higher than the latest high-bypass-ratio turbofan engine in use (ref. 5). Unfortunately, the afterburning turbojet produces a level of jet noise on take-off that is of questionable acceptability for airplanes of the 1990's and beyond.

The responsibility for the engine and inlet portions of the SCAR program are assigned to the Lewis Research Center. Both the General Electric Company and Pratt and Whitney Aircraft Group - United Technologies Corporation work under coordinated contracts with Lewis and the Langley system study contractors. The specific propulsion areas discussed are as follows:

Variable-cycle engine
Better performance
Higher temperatures
Reduced emissions
Coannular noise effect
Advanced suppressor
Advanced materials and structures

Both General Electric and Pratt and Whitney have developed concepts for advanced engines with higher airflows to help solve the noise problem. These engines can vary the airflow capability of the engine to match the varying requirements with Mach number - thus, the generic term variable-cycle engine (fig. 2). These engines act much like a turbojet at cruise and more like a turbofan for take-off and subsonic operation. The variable flow capability of these engines has provided important gains in the subsonic flight regime, particularly for subsonic missions and reserve flight conditions where the values of specific fuel consumption have been reduced by as much as 35 percent compared with a turbojet engine (fig. 3). These gains have resulted primarily from the reduction in spillage and boattail losses provided by the varying airflow capability of the variable-cycle engine.

These engines employ advanced technology in their temperature and cooling levels, their combustor technology, noise reduction, subsonic performance and, of course, in their weights. Improved efficiency combustors have provided important gains in the NO_x emissions index (fig. 4). More than a 50-percent reduction from present NO_x levels has been demonstrated in rig tests. Conceptual combustors which provide even further reductions (ref. 6) are being studied.

Both Pratt and Whitney and General Electric have determined that an inverted exhaust velocity profile can provide a 3 to 5 dB noise reduction compared with a fully mixed exhaust flow having the same airflow and thrust (fig. 5). This "coannular" effect results from having the hotter, higher velocity exhaust flow on the outside of the jet and the slower, cooler flow near the center. It has been demonstrated experimentally with both dual-flow and plug nozzles. These effects have been identified statically with small test nozzles. A significant part of the variable-cycle-engine program is directed to proving these effects with larger nozzles and with the correct temperatures and airflows representative of an actual turbine engine. Tests to confirm the noise reductions with forward velocity effects are under way. In addition, the McDonnell Douglas Corporation has developed an advanced suppressor system to provide an alternate method of noise reduction (fig. 6). They have had favorable small-scale static tests and favorable whirl-rig tests conducted in conjunction with Rolls-Royce Limited in England. They have also recently completed forward velocity tests in the Ames 40- by 80-foot wind tunnel.

These engines also use advanced material and structural techniques to achieve the projected weight levels. One of these, a titanium-fan duct is shown in figure 7. Significant reductions in cost are being demonstrated.

In total, these propulsion advances result in a range gain of about 500 n. mi. over a conventional turbojet engine.

ADVANCED AERODYNAMICS

The airplanes being studied in the SCAR program utilize wings with subsonic leading edges and optimized camber and twist for reduction in drag due to lift (fig. 8), optimum area ruling, and favorable interference effects (fig. 9) to attain supersonic cruise lift-drag ratios (L/D) between 9 and 10. The Boeing Company has applied wing-body blending (fig. 10) to their airplane which, with small planform improvements, has resulted in a 20 percent improvement in L/D. In 1977, Boeing proposed the blended wing-body "family" concept (fig. 11), which offers a solution to the airplane payload/size problem with little or no effect on the aerodynamics of the airplane. A base 270-passenger, 5-abreast airplane can be laterally stretched up to a 6-abreast configuration or down to a 4-abreast configuration with important advantages in terms of meeting customer desires without significantly affecting the aerodynamics. This concept is discussed further in the section "Advanced Concepts."

Langley in-house effort has concentrated on the low-speed area (fig. 12) to improve take-off and landing aerodynamics. Important gains have been made in keeping the flow attached on these highly swept planforms. Improved flap lift increments and near-linear pitching moments have resulted. A new problem has surfaced which indicates that the low-speed shape of these highly swept, flexible airplanes is substantially different than the cruise shape (fig. 13). The differences (5° anhedral, for instance) result in less critical rolling moments and more linear pitching moments. Tests are in progress to identify these incremental effects.

If all the aerodynamic improvements are combined, a range increase of about 500 n. mi. is obtained.

ADVANCED STRUCTURES

The most exciting advance in the structural area is probably the application of finite-element modeling (fig. 14) and advanced computational methods to these large flexible wings. Computational modules have been developed and combined to provide detailed analysis of very complex systems. An airplane structural model typically consists of over 4000 elements with 2000 degrees of freedom. This computer technology has resulted in a reduction in the structural design turn-around time from 3 months to less than a week. This means fast evaluation of innovative ideas and approaches that could not have been considered in the past. These strength-design models can be evaluated for flutter (fig. 15) in an equally fast turn-around time. Thus, the impact on flutter of items like engine mass and location, engine support beam stiffness, or presence of wing fuel can be determined quickly and reliably.

A spin-off of the Rockwell International B-1 program - superplastic forming and concurrent diffusion bonding of titanium (SPF-DB) - is another

promising new structural area (ref. 1). Figure 16 shows two types of titanium structure. One began as two flat titanium sheets which were bonded together and formed into skin, ribs, and stringers, concurrently. The other was a four-sheet complex-core sandwich somewhat similar to honeycomb. These techniques promise large weight and cost reductions - studies for application in specific areas have resulted in 10- to 30-percent weight reductions with cost savings of over 50 percent.

Significant effort has gone into studying the various forms of high-temperature polyimide composite structures (fig. 16). Initial studies indicate even larger weight savings than the SPF-DB titanium.

Langley, Boeing, and McDonnell Douglas have all studied active-control landing gears (fig. 17). Each used different approaches and had different degrees of success. The studies have progressed to the point, however, that active gears are almost a certainty on the long-fuselage supersonic cruise type airplane because of significant payoffs in terms of sensitivity to runway roughness, horizontal tail size required for rotation, and even aft center-of-gravity limits.

It is believed that the incorporation of the structure technology gains could result in an 8- to 10-percent reduction in operating empty weight or a gain in range of about 300 n. mi.

ADVANCED PROCEDURES FOR NOISE REDUCTION

Some of the most exciting work coming out of the SCAR program involves an understanding that an SST does not want to take off and land with the same rules as its subsonic counterpart; the SST wants to behave differently (fig. 18). First, recognize that in contrast to a subsonic aircraft, where they are all fixed, the engine, inlet, and nozzle on an SST have a significant degree of variability. It follows naturally that if this variability is utilized, important noise reductions may occur.

During take-off from brake release until approximately wheels-up, sideline noise is favorably affected by forward velocity effects and ground attenuation. For a constant throttle setting, maximum noise normally occurs as the airplane climbs out of ground attenuation at an altitude of about 213 m (700 ft) (fig. 19). With an auto-throttle procedure, increasing the throttle about 15 percent from brake release until the altitude was reached where the maximum sideline noise would normally occur would result in the aircraft reaching that point at a higher velocity and/or altitude with no increase in sideline noise. Furthermore, flap settings may also be automated, since they are simple plain flaps. The combination of reduced flap settings and increased velocity results in a cut-back L/D that has increased to more than 10 compared with a normal value of around 7. Present results indicate noise over the community may be reduced 5 to 7 dB by these different procedures. Significantly, in these deeper cut-back cases jet noise may no

longer dominate; other sources such as compressor, fan, or shock noise become important.

On the approach end of the runway, equally exciting things are possible by use of decelerating approaches and increased glide slopes. On a 3° glide slope, for instance, the decelerating approach reduces noise by 4 or 5 dB. Further, each 1° increase in glide slope reduces noise about 2 dB. Increases in glide slopes may be possible for an SST because of the large favorable ground effect produced by the low-aspect-ratio wing. During landing, jet noise is small. Inlet choking and duct treatment are required to quiet the other engine noise sources. Airframe noise itself becomes a significant factor.

The most important result of these studies is that important gains in noise reduction are possible when we understand the airplane and how it can be operated safely to reduce noise. Another important feature is the decrease in noise as the airplanes are operated at reduced payloads and/or reduced gross weights. Because the SST has such a large fuel fraction, reduced weight operations become particularly important. Perhaps the best proof lies in the Concorde experience at John F. Kennedy International Airport, where the Concorde operates at a take-off gross weight approximately 10 433 kg (23 000 lb) less than the take-off gross weight from Dulles International Airport. During the first three months, the flight measurements have indicated an average noise level at the monitor stations of 96.5 EPNdB (refs. 7 to 9), which is well below the 108-dB FAR 36 requirements (ref. 10) and far below the 117-dB levels demonstrated at Dulles.

CONCLUDING REMARKS

Based on the technologies just reviewed, it is reasonable to project some of the characteristics of advanced supersonic systems. There will be families of supersonic aircraft just as there have been families of subsonic aircraft. For supersonic aircraft, however, the stretch or shrink will be lateral instead of longitudinal. This will enable a variety of payloads and ranges to be obtained with most of the expensive parts of the aircraft remaining constant between the various models. This stretch capability will make possible greater market penetration, longer and larger production runs, and reduced cost. The variable-cycle engine, the reduced structural weight, and improved aerodynamics will provide large payload range capability. For the first time, supersonic ranges in excess of 5000 n. mi. can be considered. If the coannular noise effect and the automated take-off and landing procedures identified in the SCAR program can be substantiated at full-scale operating conditions, the airplane will be capable of attaining stringent noise goals. These advanced airplanes will utilize hardened stability augmentation systems which will allow the center of gravity to be aft of the neutral point and still provide superior pilot handling characteristics. If necessary, it will be feasible to implement an active flutter suppression system. The economics of such

an airplane would make it very competitive with the subsonic wide bodies of a similar size.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
April 28, 1978

REFERENCES

1. Proceedings of the SCAR Conference - Parts 1 and 2. NASA CP-001, [1977].

2. Grobecker, A. J.; Coroniti, S. C.; and Cannon, R. H., Jr.: Report of Findings - The Effects of Stratospheric Pollution by Aircraft. TST-75-50, U.S. Dep. Transp., Dec. 1974. (Available from DDC as AD A005 458.)

3. Oliver, R. C.; Bauer, E.; Hidalgo, H.; Gardner, K. A.; and Wasylkiwskyj, W.: Aircraft Emissions: Potential Effects on Ozone and Climate - A Review. FAA-EQ-77-3, Mar. 1977. (Available from DDC as AD A040 638.)

4. Broderick, Anthony J.: Stratospheric Effects From Aviation. [Paper] 77-799, American Inst. Aeronaut. & Astronaut., July 1977.

5. Calder, P. H.; and Gupta, P. C.: The Application of New Technology for Performance Improvement and Noise Reduction of Supersonic Transport Aircraft. [Paper] 77-830, American Inst. Aeronaut. & Astronaut., July 1977.

6. Aircraft Engine Emissions. NASA CP-2021, 1977.

7. Monitoring of Concorde Operations at John F. Kennedy International Airport During October 1977. FAA, U.S. Dep. Transp., Nov., 3, 1977.

8. Monitoring of Concorde Operations at John F. Kennedy International Airport During November 1977. FAA, U.S. Dep. Transp., Dec. 13, 1977.

9. Monitoring of Concorde Operations at John F. Kennedy International Airport During December 1977. FAA, U.S. Dep. Transp., Jan. 12, 1978.

10. Noise Standards: Aircraft Type Certification. Federal Aviation Regulations, vol. III, pt. 36, FAA, Dec. 1969.

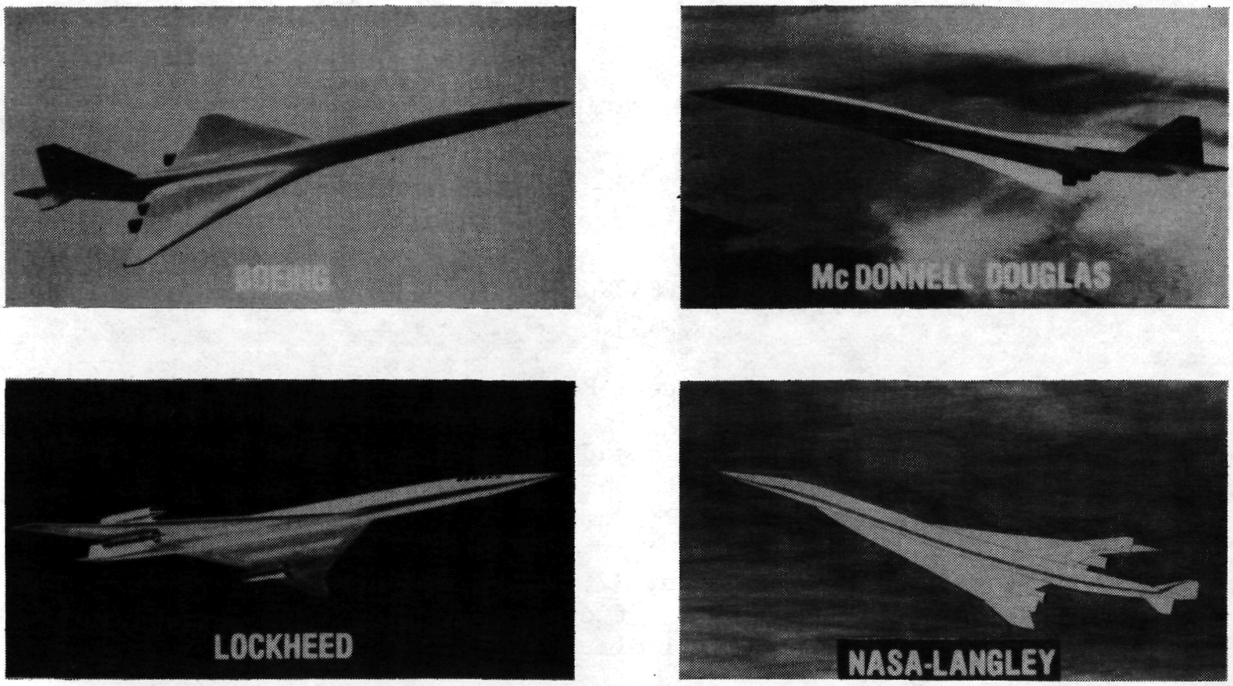

Figure 1.- Advanced supersonic cruise aircraft configurations.

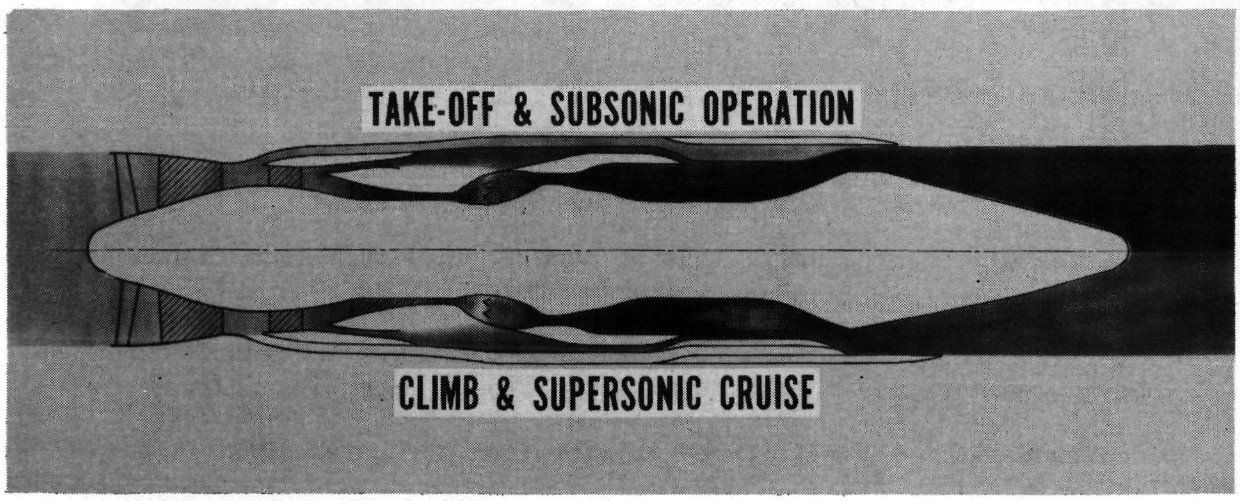

Figure 2.- Variable-cycle engine.

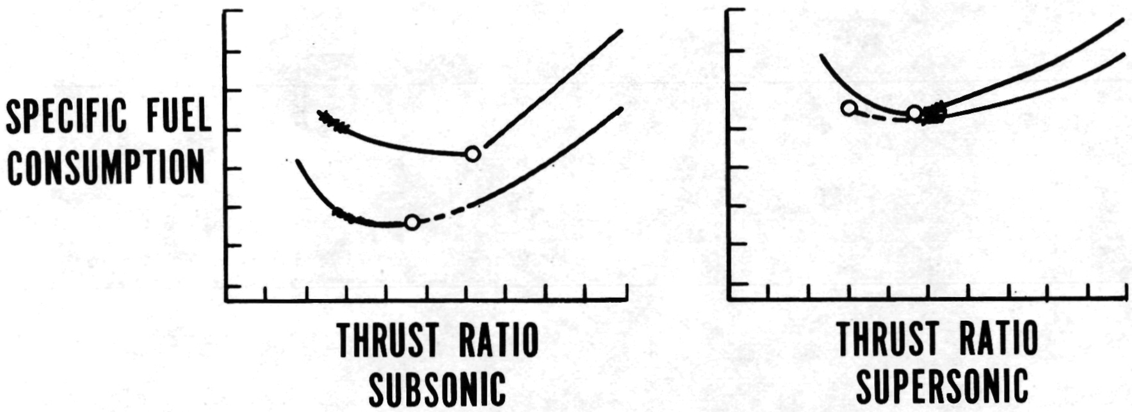

Figure 3.- Better engine performance.

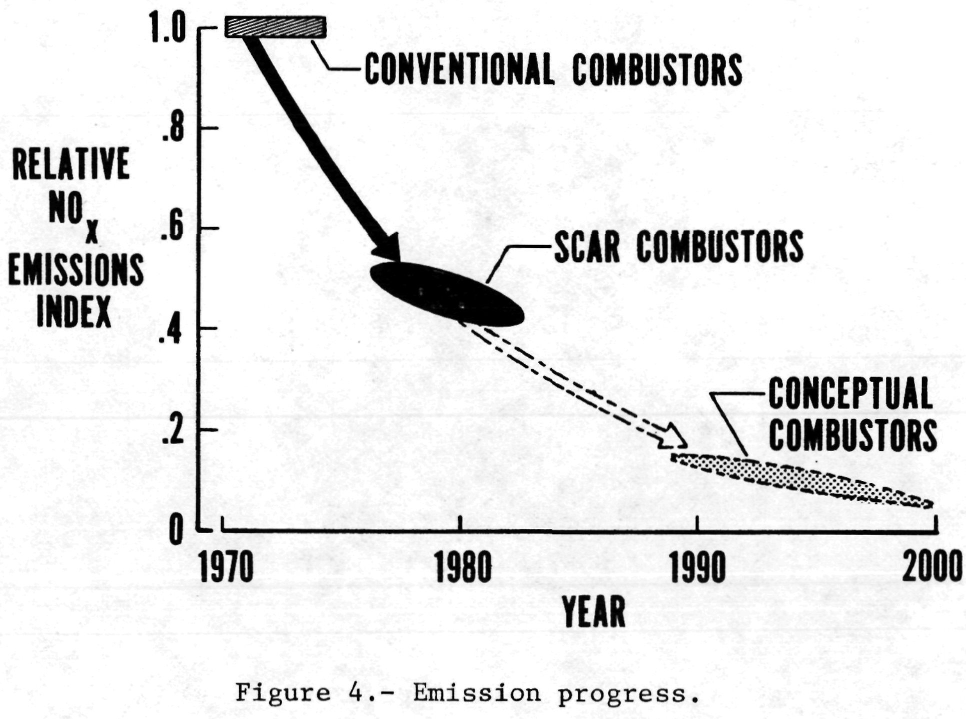

Figure 4.- Emission progress.

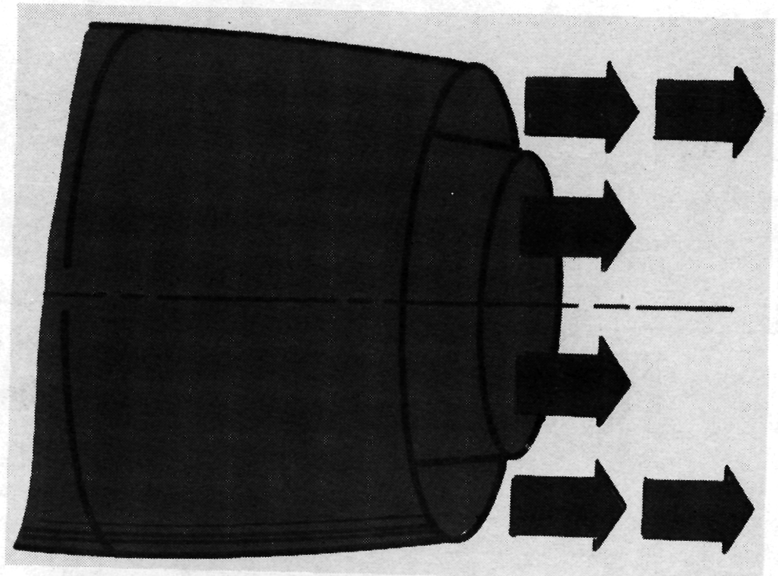

Figure 5.- Coannular noise effect.

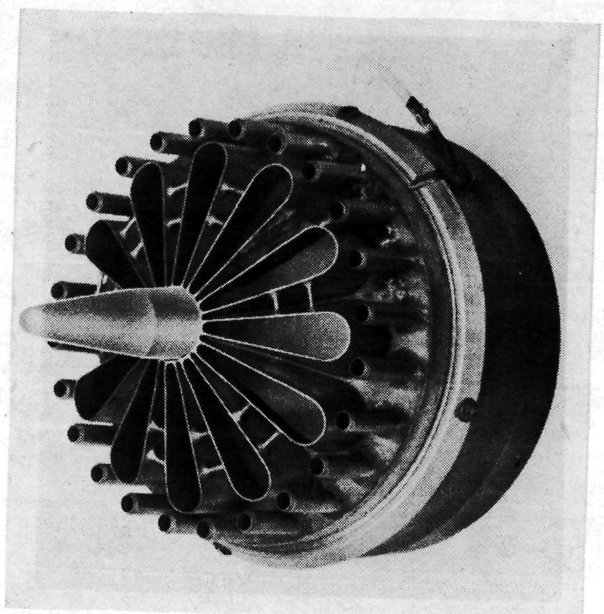

Figure 6.- Advanced suppressor.

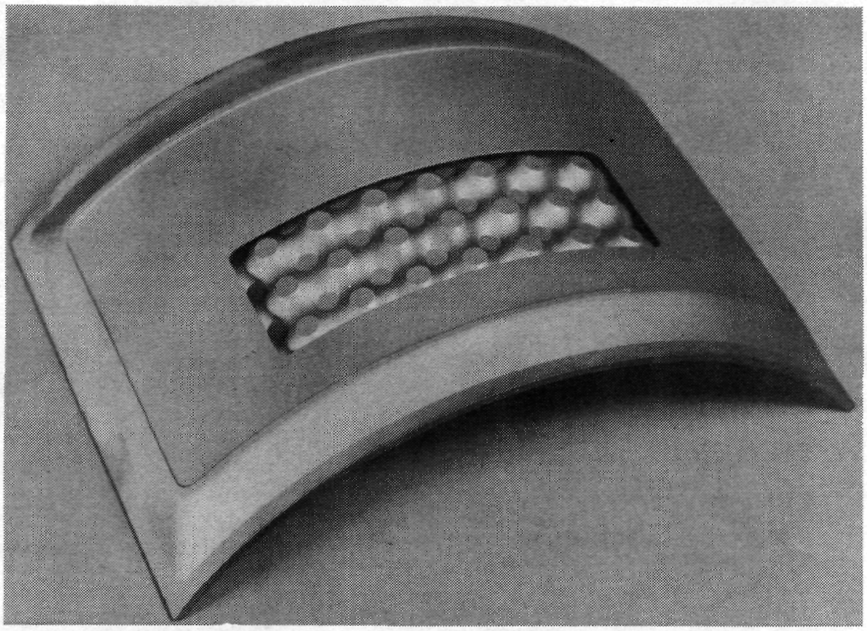

Figure 7.- Advanced structures.

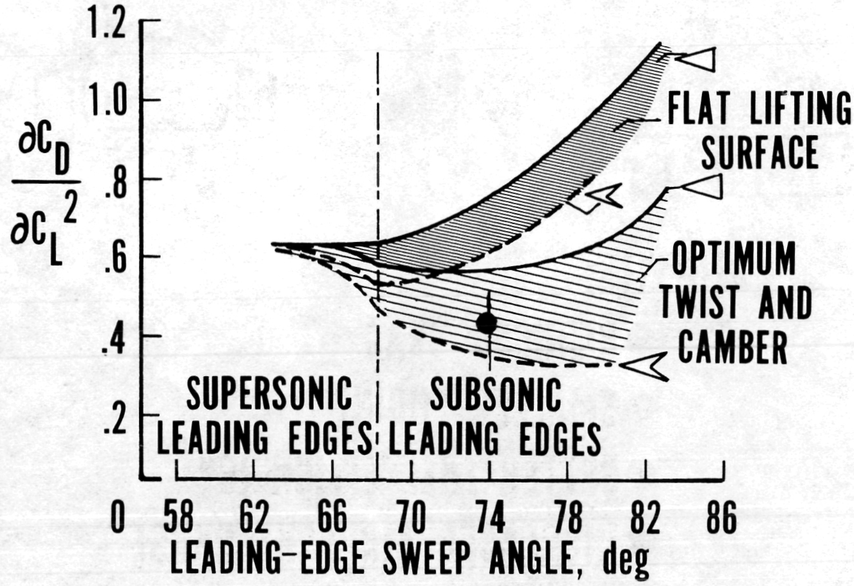

Figure 8.- Wing design considerations at a Mach number of 2.7. (Variation of drag-due-to-lift parameter with sweep angle.)

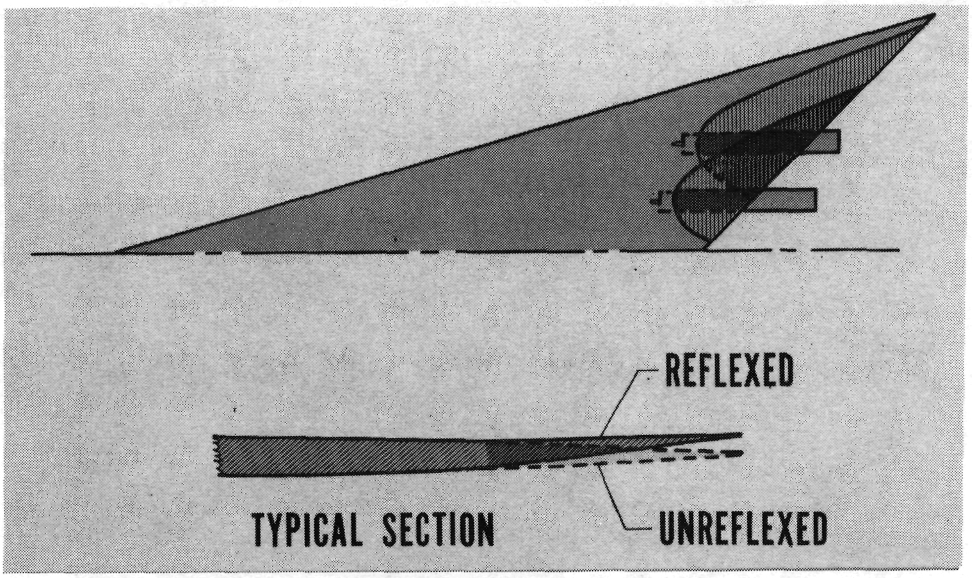

Figure 9.- Favorable interference.

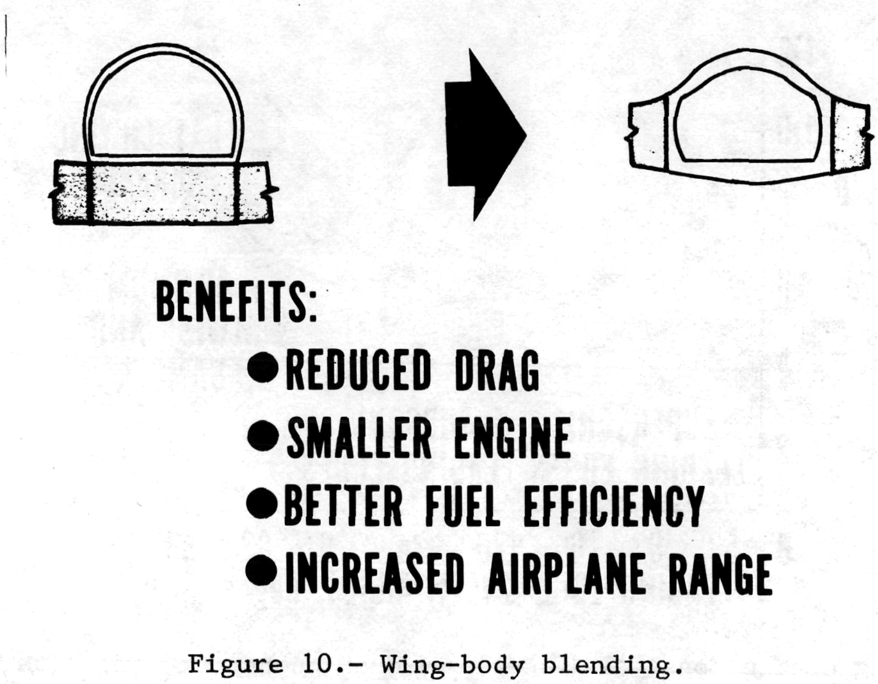

Figure 10.- Wing-body blending.

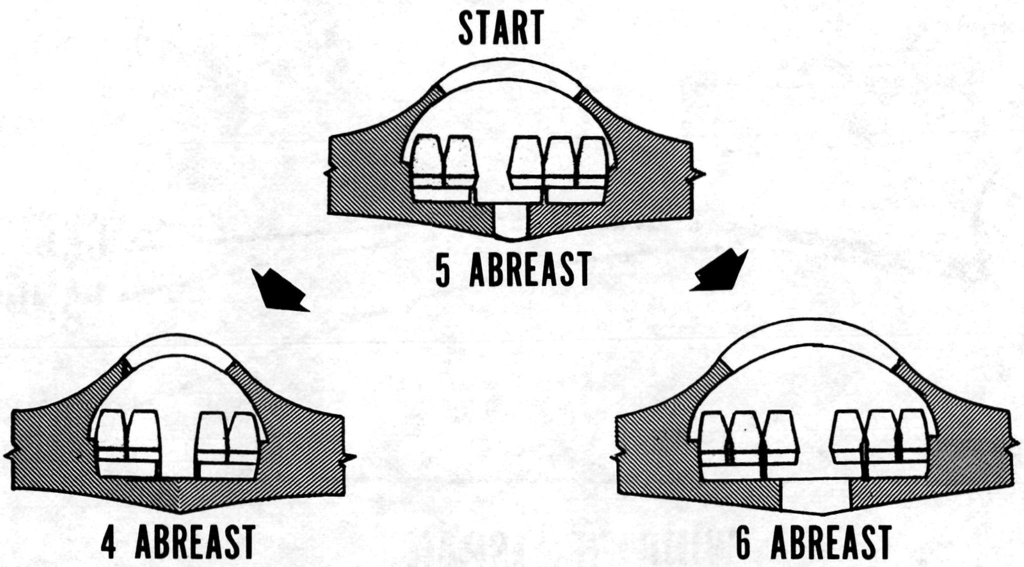

Figure 11.- Family concept.

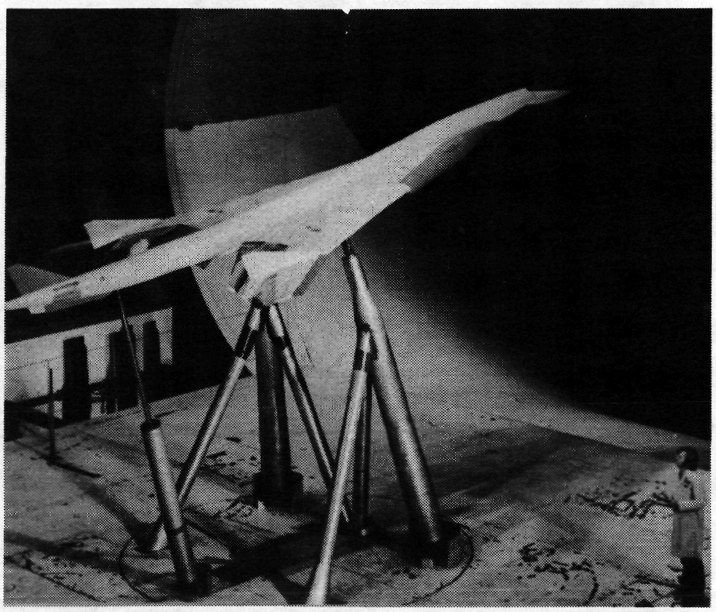

Figure 12.- Low-speed wind-tunnel model.

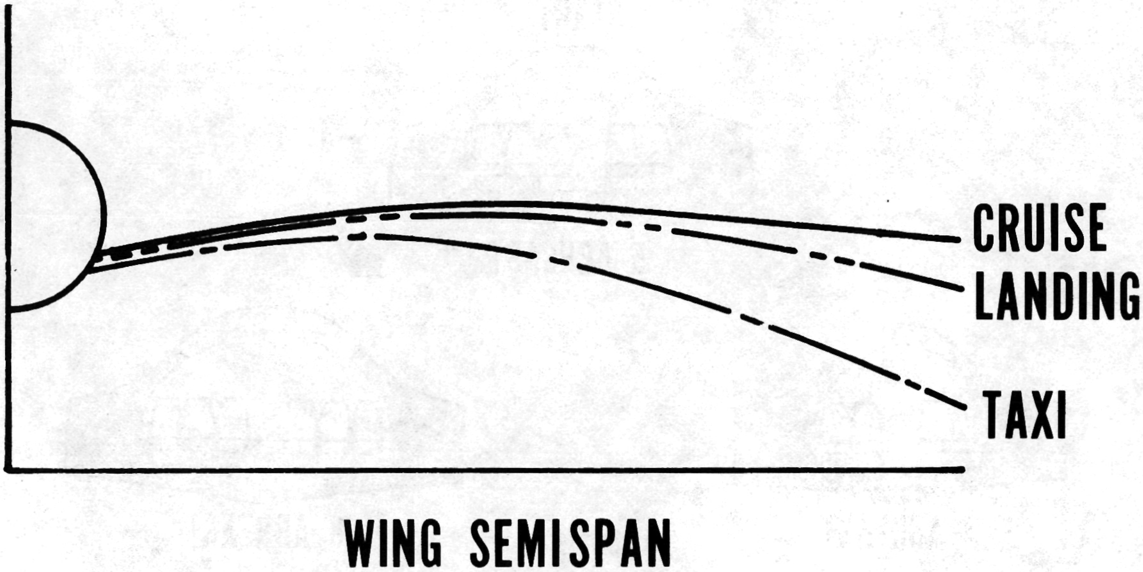

Figure 13.- Wing semispan shape.

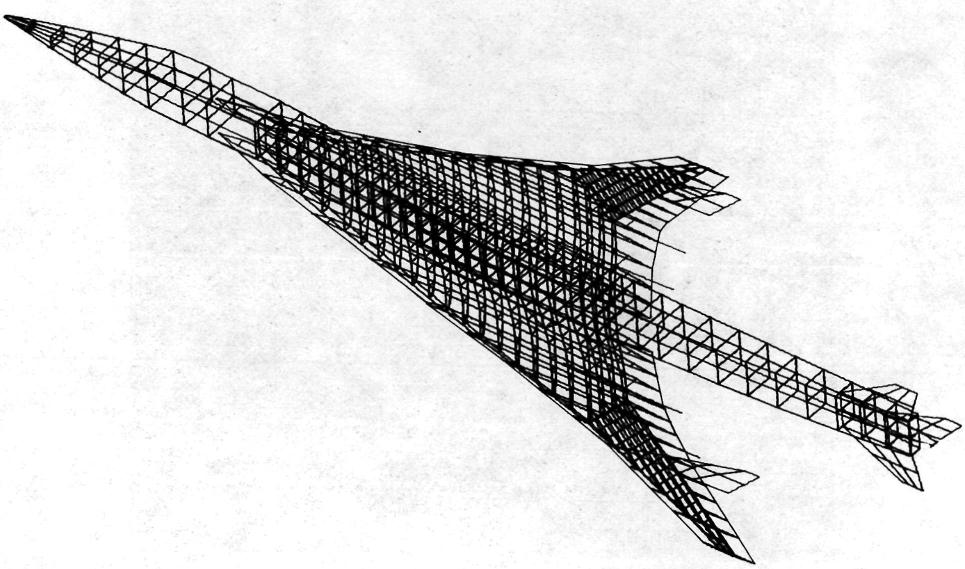

Figure 14.- Finite-element model.

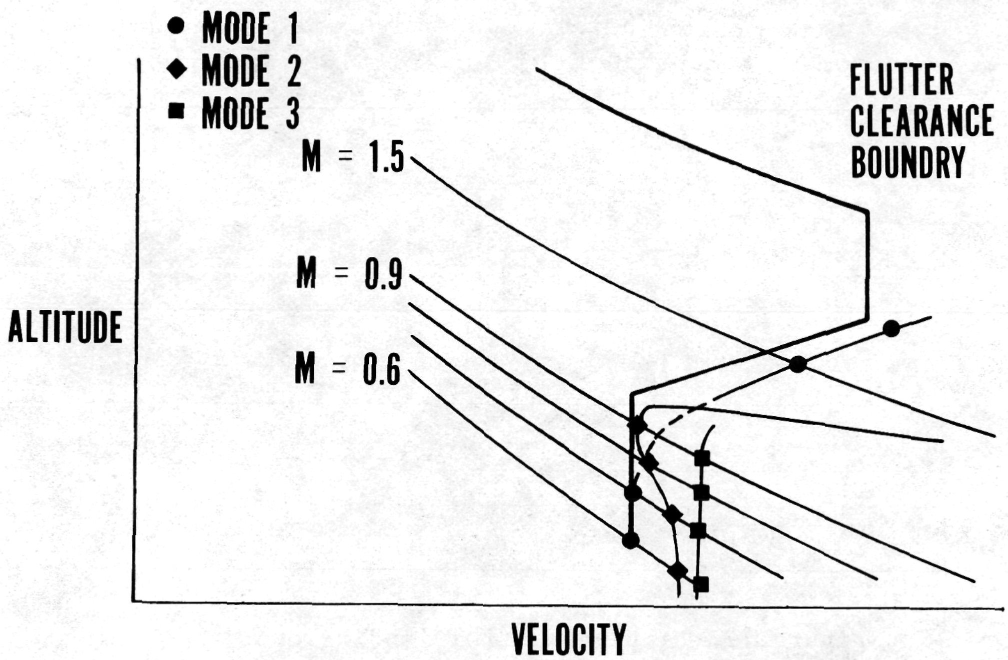

Figure 15.- SCAR arrow wing flutter results at various Mach numbers M.

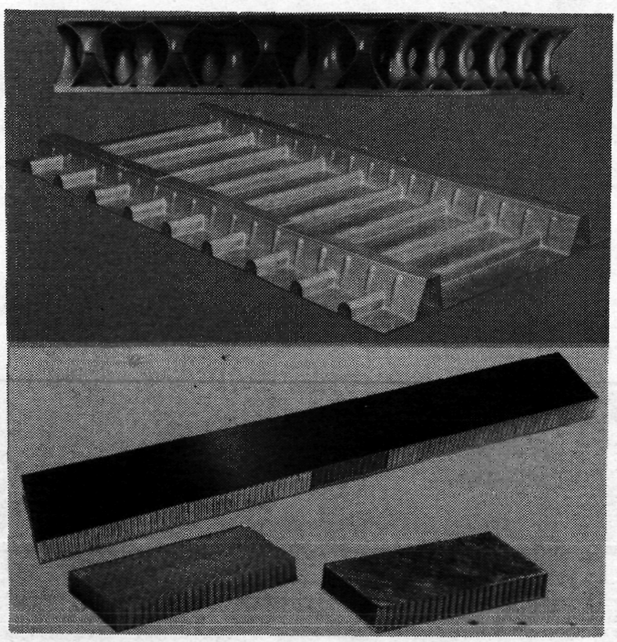

Figure 16.- Advanced materials.

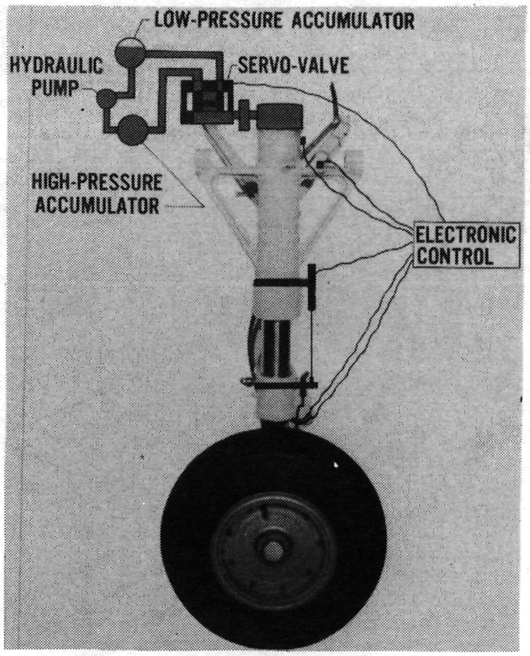

Figure 17.- Active-control landing gear.

LANDING

- DECELERATING APPROACH
- INCREASED GLIDE SLOPE
- INLET CHOKING

TAKE-OFF

- INCREASED THRUST DURING GROUND ROLL (GROUND ATTENUATION)
- AUTO THROTTLE
- AUTO FLAPS
- ACCELERATION/ALTITUDE

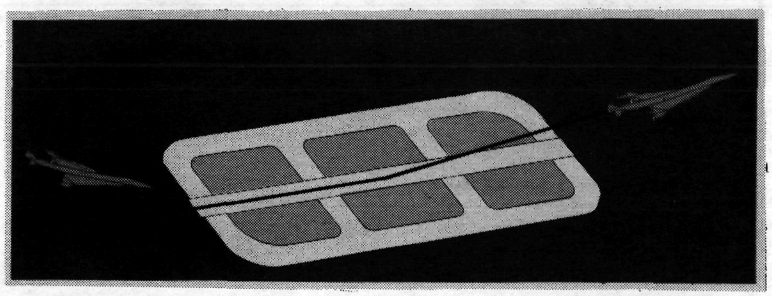

Figure 18.- Advanced procedures for noise reduction.

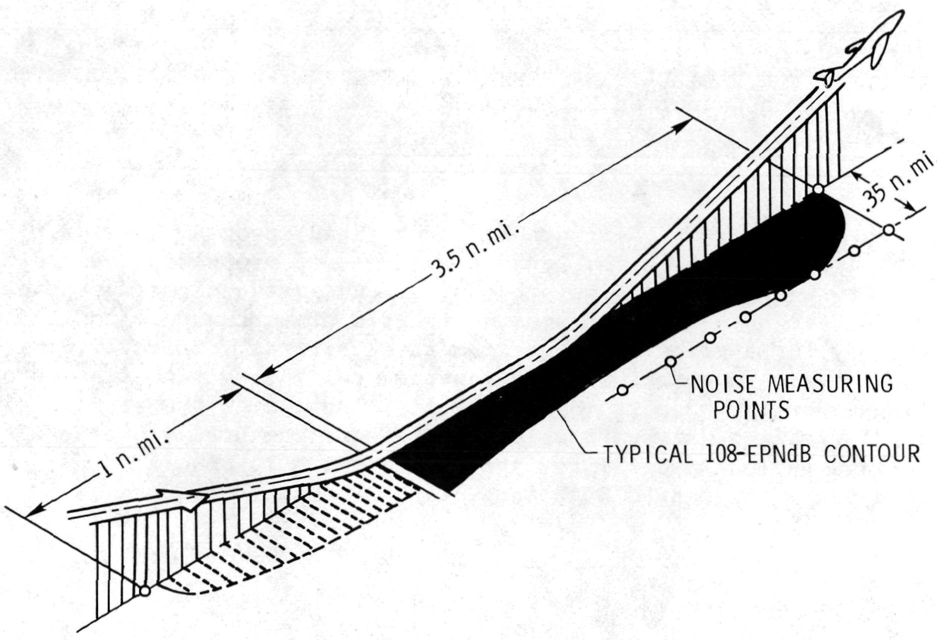

Figure 19.- Airport and community noise contours.

1. Report No. NASA TM-78695	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PROGRESS IN SUPERSONIC CRUISE AIRCRAFT TECHNOLOGY		5. Report Date May 1978
		6. Performing Organization Code
7. Author(s) Cornelius Driver		8. Performing Organization Report No. L-12274
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		10. Work Unit No. 516-50-23-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

This paper was presented at the CTOL Transport Technology Conference held at Langley Research Center on February 28 to March 3, 1978, and is published in NASA CP-2036.

16. Abstract

The Supersonic Cruise Aircraft Research (SCAR) program has identified significant improvements in the technology areas of propulsion, aerodynamics, structures, take-off and landing procedures, and advanced configuration concepts. These technology areas require significant further development before they are ready for application to a commercial aircraft. However, they may answer the adverse factors that were instrumental in the cancellation of the National Supersonic Transport (SST) program. They offer the promise of an advanced SST family of aircraft which may be environmentally acceptable, have flexible range-payload capability, and be economically viable. Further development requires an augmented SCAR technology program.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Supersonic Cruise Aircraft Technology Propulsion Aerodynamics, structures Advanced configuration concepts Take-off and landing procedures	Unclassified - Unlimited Subject Category 01

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	17	$4.00

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1978

7/29/79 ~~D. Miller 341/33/2 3425~~

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

~~Ray Herring 380/33/600/3425~~

22 JAN 80 V.E. Mulliken E241/10/M/E31/ MS 51